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# Assessing Indoor Air Pollution Exposure and Lung Cancer Risk in Xuan Wei, China

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16. ABSTRACT

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# Assessing Indoor Air Pollution Exposure and Lung Cancer Risk in Xuan Wei, China

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## ABSTRACT

**This report presents the risk-assessment-related aspects of a multidisciplinary study of indoor coal smoke pollution and lung cancer in Xuan Wei County, Yunnan Province, China. Xuan Wei presents a unique natural experiment in environmental carcinogenesis because lung cancer mortality rates and indoor pollution exposures vary widely within the County. Current evidence links lung cancer with domestic burning of "smoky coal," as opposed to "smokeless coal" and wood. Efforts to determine the most carcinogenic components of smoky coal pollution are in progress, as are efforts to develop a quantitative relationship of pollution dose with lung cancer response in Xuan Wei. Some available evidence suggests that the composition of indoor pollution does not vary greatly throughout Xuan Wei, and thus that lung cancer risk is a function of overall pollution exposure. Other evidence suggests that different Xuan Wei fuels exhibit different carcinogenic potencies. On-site and laboratory studies are being conducted to differentiate between these possibilities.**

## INTRODUCTION

THIS REPORT PRESENTS RISK-ASSESSMENT-related aspects of a multidisciplinary study of indoor air pollution and lung cancer in Xuan Wei County, Yunnan Province, China. This study is being conducted jointly by investigators from the Chinese National Academy of Preventive Medicine and the U.S. Environmental Protection Agency, under the China–U.S. Protocol for Scientific and Technical Cooperation in the Field of Environmental Protection. This paper

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The research described in this article has been reviewed by the Health Effects Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

describes the unusual research setting that Xuan Wei offers, summarizes some major (and sometimes somewhat contradictory) trends in findings to date, and outlines some of the main research goals and issues confronting present and future research in this project. Although the project has yielded interesting results to date, it is still in midcourse, with major challenges and major learning opportunities still ahead. This paper will conclude by emphasizing research challenges rather than interpreting available results.

## RESEARCH SETTING

The setting for this cooperative research is Xuan Wei County, a rural county with about 1 million people situated in Yunnan Province in southern China. Over 90% of Xuan Wei residents are farmers, although there a few local industries such as chemical fertilizer plants and a cement plant. There are also several national coal mines that supply coal to other parts of Yunnan and other provinces. Xuan Wei, like much of Yunnan Province, is rich in coal. The Xuan Wei population is very stable; fewer than 20% of households have residents who have moved into or out of the county.

In 1979 the Chinese government published a nationwide atlas of annualized mortalities from many different kinds of cancers in each of China's 2000 counties and municipalities from 1973 through 1975.[1] As shown in Table 1, Xuan Wei was remarkable in exhibiting very high lung cancer mortality in both male and female residents; indeed, the lung cancer mortality rate among female residents was the highest in China, despite the fact that Xuan Wei is a rural, isolated county. This finding was especially noteworthy in view of the fact that in Yunnan Province as a whole, lung cancer mortality is far lower than the Chinese national average. The overall similarity of male and female subjects' lung cancer mortality rates in Xuan Wei was striking. Also remarkable was the fact that lung cancer was the only type of cancer for which mortality exceeded the national average in Xuan Wei; indeed, most types of cancer exhibited mortality rates well below the national average.

On the basis of these initial observations, it appeared that some factor or set of factors was predisposing Xuan Wei residents specifically to lung cancer. The results of numerous studies worldwide naturally caused a great deal of suspicion to fall on tobacco smoking. Over the last decade there have been several surveys of tobacco smoking habits in Xuan Wei, and all of them indicate that men smoke heavily throughout the county but that women hardly smoke at all. It therefore seemed that tobacco smoking might well contribute to lung cancer in men, but that it could not explain the high lung cancer rates observed in women.

For generations Xuan Wei residents have used one or more of three different kinds of fuels for domestic heating and cooking, depending on the part of the county in which they lived. These fuels are so-called "smoky coal," so-called "smokeless coal," and wood. Smoky coal is glossy black, contains less than 1% sulfur, and, as its name implies, smokes heavily on firing. Smokeless coal is dull black, smokes little on firing, and crumbles so easily that it is necessary to mix it with clay for it to hold its shape for burning. Its sulfur content is relatively high, occasionally exceeding 5%. Smokeless coal deposits occur in the southwestern region of Xuan Wei. Smoky coal is deposited in much of the rest of the county. Wood has been used most commonly near the county border, and its use has decreased over the years with deforestation. In most cases, families that use coal obtain it from within a few kilometers of their homes.

Throughout Xuan Wei, until this decade, virtually all domestic fuel burning for heating and cooking was done in a simple, unvented firepit in the floor of the family residence's main room. The lack of ventilation allowed very high concentrations of smoke to fill the home. In some homes, total particulate levels in excess of 20 mg/m$^3$ have been measured. Starting the fire in the morning and cooking have traditionally been women's tasks in Xuan Wei. While both men and women spend much time in farming, women generally spend more time inside the home than men.

TABLE 1. ANNUAL LUNG CANCER MORTALITY RATES IN CHINA AND THE UNITED STATES

| *Place and time period* | *Lung cancer mortality rate, per 100,000* | | | | | |
|---|---|---|---|---|---|---|
| | *Unadjusted* | | *Age-adjusted to 1964 China population* | | *Age-adjusted to 1970 U.S. population* | |
| | *Males* | *Females* | *Males* | *Females* | *Males* | *Females* |
| China, 1973–1975 | 5.0[a] | | 6.8 | 3.2 | 12.3 | 5.7 |
| U.S., 1970 | 53.7 | 12.0 | 30.0 | 6.3 | 53.7 | 12.0 |
| Yunnan Province, 1973–1975 | 2.8[a] | | 4.3 | 1.5 | 6.9 | 2.5 |
| Xuan Wei County, 1973–1979 | 27.0 | 24.5 | 27.7 | 25.3 | 43.2 | 38.7 |
| Three Xuan Wei communes of highest lung cancer mortality (Cheng Guan, Lai Bin, Rong Cheng) 1973–1979 | 114.4 | 120.6 | 118.0 | 125.6 | 186.8 | 193.4 |
| 55-59 year age group in high-mortality communes | 849.4 | 904.0 | | | | |
| Three Xuan Wei communes of low lung cancer mortality (Pu Li, Yang Liu, Re Shui) 1973–1979 | 4.0 | 2.8 | 4.3 | 3.1 | 5.8 | 4.3 |
| 55–59 year age group in low-mortality communes | 17.1 | 18.1 | | | | |

[a]Unadjusted rate for both sexes combined.

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Xuan Wei County is divided into 20 communes. Figure 1 is a map of the county, showing commune boundaries and for each commune, the annual unadjusted lung cancer mortality per 100,000 population, in both sexes from 1973 through 1975.[2] The figure also shows the locations of smoky and smokeless coal mines that supply coal for domestic use. Two communes near the center of the County, with high lung cancer mortalities of 151.8 and 93.0, do not have smoky coal mines, but over 90% of their residents are known to use smoky coal from the commune directly to the north, and there is a mortality rate of 109.3.

Two interesting observations emerge from this figure. First is the tremendous variation in lung cancer mortality from commune to commune. That the average commune population is about 50,000, and that commune-specific lung cancer mortalities in 1976 to 1979 were similar to those shown in Figure 1 indicate that this variation is stable. This variation offers a most unusual opportunity for epidemiologic determination of the factors responsible for lung cancer, and for development of dose–response relationships of air pollution levels with lung cancer risk.

The second observation to be derived from Figure 1 is that in communes with smoky coal mines (including the two central communes mentioned above), lung cancer mortality is generally substantially higher than in communes without smoky coal mines. In 1973 through 1975 the average mortality in communes with smoky coal mines was 34.7:100,000, and in other communes it was only 4.1:100,000.

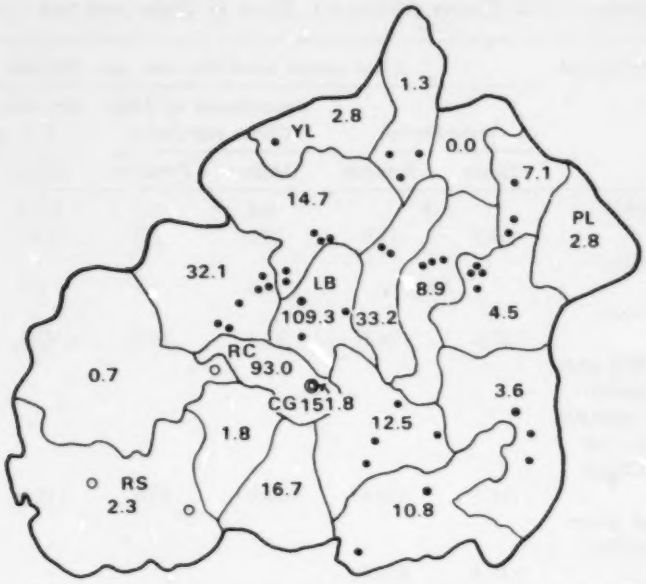


**FIG. 1.** Map of Xuan Wei County, showing commune boundaries, each commune's unadjusted annual lung cancer mortality rate per 100,000 (both sexes, 1973–1975), and mines supplying domestic coal: (●) smoky coal and (○) smokeless coal. Designated communes: CG, Cheng Guan; LB, Lai Bin; PL, Pu Li; RS, Re Shui; RC, Rong Cheng; and YL, Yang Liu (reprinted by permission from ref. [2], copyright 1987 by the AAAS).

In 1982 Chinese researchers conducted a survey of fuel use habits in several communes prior to 1958 (at least 15 years before the lung cancer mortality figures presented in Fig. 1). In Figure 2, the percentage of households using smoky coal before 1958 in 11 communes is plotted against the annual unadjusted lung cancer mortality in each of these communes from 1973 through 1975. A least-squares linear regression line has also been fitted to the data. The figure shows a strong association of lung cancer mortality with smoky coal use; even in this straight-line relationship, the correlation coefficient is 0.82, which is statistically significant at alpha = 0.001. When curvilinear functions are fitted to these data, the association becomes even stronger.

These observations suggest strongly that indoor combustion of smoky coal is a major determinant of lung cancer in Xuan Wei. Another observation supporting this view is that no positive association of lung cancer with nonagricultural occupations has been detected in surveys conducted to date.

## TRENDS IN RESULTS TO DATE

On balance, there is little doubt that burning smoky coal plays an important role in the production of lung cancer in Xuan Wei. A case–control study, designed to quantitate the importance of smoky coal use relative to other factors such as tobacco smoking, occupation, diet, and other environmental factors, is now in progress. Studies to determine the specific chemical/physical basis of the relationship between lung cancer and fuel use are also underway.

The chemical composition of combustion products may not change greatly among smoky coals mined in different areas in Xuan Wei, or even among the three different fuel types

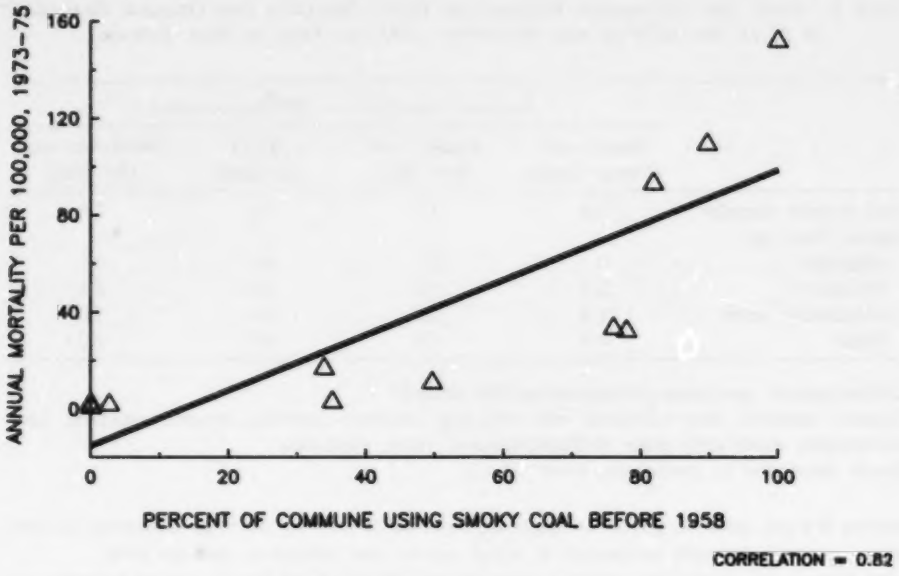


**FIG. 2.** Relationship of percentage of households burning smoky coal before 1958 with annual unadjusted lung cancer mortality (1973–1975) in 11 Xuan Wei communes.

described above (smoky coal, smokeless coal, and wood). If this were true, the lung cancer risk conferred by indoor air pollution in Xuan Wei could be a relatively simple function of the bulk dose of combustion products received by the individual. Some observations to date appear to be consistent with such a dose–response relationship. For example, Figure 2 shows a close relationship of the percentage of households burning smoky coal with subsequent lung cancer mortality. These data suggest that the more of any smoky coal smoke an individual breathes, the more likely he or she is to develop lung cancer. The figure suggests in turn that the general chemical composition of smoky coal combustion products may not differ greatly among smoky coals from different mines.

Some of the Ames test findings to date are also consistent with such a "bulk dose" type of dose–response relationship. In Xuan Wei, indoor air pollution samples were collected onto filters in two homes burning smoky coal, one home burning smokeless coal, and one home burning wood. Ames tests were conducted on the methylene-chloride-extractable portions of the pollution samples.

Table 2 presents the Ames test mutagenic potencies of these pollution samples, expressed per milligram of sample and therefore adjusted for pollution concentration.[3] For no fuel did the aliphatic fraction show mutagenic potency. Also, the fuel-to-fuel differences in potency within the aromatic and moderately polar fractions were unexpectedly small in view of the large differences in lung cancer mortality among communes using different fuel types. Thus, the results for the aliphatic, aromatic, and moderately polar fractions suggest a similar chemical composition among the different Xuan Wei fuel types, and are therefore consistent with a "bulk dose" type of dose–response relationship.

The mutagenic potencies within the total organic samples and the polar fractions differed more widely than within the aliphatic, aromatic, and moderately polar fractions. Even in the whole samples and the polar fractions, the potencies of the smoky coal and smokeless coal

TABLE 2. AMES TEST MUTAGENIC POTENCY OF TOTAL ORGANICS AND ORGANIC FRACTIONS OF XUAN WEI INDOOR AIR POLLUTION, 1983, BY TYPE OF FUEL BURNED

| | *Potency (revertants × 1000/mg sample)* | | | |
|---|---|---|---|---|
| | *Smoky coal (Cheng Guan)* | *Smoky coal (Lai Bin)* | *Wood (Re Shui)* | *Smokeless coal (Re Shui)* |
| Total organic sample[a] | 2.6 | 3.3 | 0.9 | 2.6 |
| Organic fractions[b] | | | | |
| Aliphatic | 0 | 0 | 0 | 0 |
| Aromatic | 2.1 | 3.2 | 3.4 | 2.5 |
| Moderately polar | 1.4 | 2.4 | 2.6 | 3.0 |
| Polar | 4.0 | 5.6 | 0.5 | 2.0 |

[a]Unfractionated methylene-chloride-extractable sample.
[b]Organic fractions were extracted with different solvents: aliphatic, hexane; aromatic, hexane/benzene; moderately polar, dichloromethane; polar, methanol.
*Source:* Reprinted by permission from ref. (3).

samples did not differ as greatly as might be expected in view of the large differences in lung cancer mortality between communes in which smoky and smokeless coal are used.

On balance, the Ames test mutagenic potencies of different Xuan Wei fuels were more similar than might have been expected. Thus, if the broad assumption is made that Ames test results are a reasonable predictor of human lung cancer experience, the Ames test results suggest that lung cancer risk in Xuan Wei may be a function of the bulk dose of combustion products received by the individual, whether that dose comes from smoky coal, smokeless coal, or even wood smoke.

However, two other available observations are not consistent with a bulk dose type of dose–response relationship. First, there is one commune, not included in Figure 2, in which over 90% of households used smoky coal before 1958, but in which the annual lung cancer mortality in 1973–1975 was only 8.9:100,000. Preliminary laboratory results suggest that combustion of smoky coal from this commune generates overall pollution levels similar to those observed when coals are burned from communes with much higher lung cancer mortalities. This observation suggests in turn that the carcinogenicity of smoky coal may vary from region to region in Xuan Wei, and thus that there may be specific carcinogens in some regions but not in others.

Preliminary results of the case–control study also suggest that lung cancer risk in Xuan Wei is not a simple function of bulk pollution dose. As mentioned above, lung cancer mortality is generally much higher in communes with smoky coal mines than in communes without them. This observation would suggest that the odds ratios associated with smoky coal use in the case–control study would be high.

Preliminary odds ratios from the case-control study are presented in Table 3. These ratios tend to incriminate smoky coal, because they are generally well above 1.0, and because they tend to increase with increasing duration of smoky coal use. However, they are lower than expected in view of the fact that in studies of smoking and cancer, the smoking-associated odds ratios often exceed 15. Also unexpected is the fact that in Xuan Wei the interim odds ratios associated with smoky coal use are not consistently higher in women than in men, even though women generally spend more time near the fire than do men.

TABLE 3. INTERIM ODDS RATIOS ASSOCIATED WITH SMOKY COAL USE NOW, 20 YEARS AGO, AND AT AGE 12 IN XUAN WEI LUNG CANCER PATIENTS AND CONTROLS

| *Time using smoky coal* | *Males (33 pairs)* | *Females (39 pairs)* |
|---|---|---|
| Now | 1.5 | 2.0 |
| 20 years ago | 1.3 | 2.9 |
| At age 12 | 4.0 | 3.7 |

*Source:* Reprinted by permission from ref. (3)

## FUTURE RESEARCH CHALLENGES

In summary, some results to date suggest that lung cancer risk in Xuan Wei may be a function of the bulk dose of indoor pollutants received by the individual, while other results suggest that the most potent carcinogens may be concentrated in fairly specific locales in the county. Indeed, smoky coal itself may not be homogeneous from mine to mine, and smoky coal's combustion products therefore may not be homogeneous from region to region within Xuan Wei.

Thus, it will be a challenging task to develop accurate and specific relationships of Xuan Wei lung cancer risk with the dose of indoor pollution received by residents. This challenge is being addressed by laboratory and on-site studies. In the laboratory, the combustion products of different Xuan Wei fuels are being compared as minutely as technology and budgets will allow. This phase of effort is scheduled for completion in 1990.

A preliminary on-site study, in which indoor air was monitored in homes for 3 consecutive days, has already been conducted by Chinese investigators. Results of this study disclose that even the within-home variation in pollution levels is substantial. For example, in one home in which smoky coal was burned, inhalable particulate levels ranged from 0.620 to 1.506 mg/m$^3$ on three consecutive summer mornings.

An on-site pilot dose–response study is also nearing completion. One of the main goals of the pilot is to identify and characterize further the many sources of variation in indoor pollution levels that must be taken into account in developing accurate dose–response relationships. In addition to further characterization of within-home variation, the pilot study is intended to measure several other types of temporal and spatial variation in indoor pollution levels. For instance, seasonal variation and variation at different times of day (for example, when the fire is started in the morning compared to when it is banked at night) will be measured. Variation from room to room in the same house, variation among homes with different architectures, and variation among homes in different locations will also be assessed. Air exchange rates and radioactivity are also being measured in Xuan Wei homes. Standardized questionnaires are being administered to ascertain activity patterns, histories of active and passive smoking, and other relevant characteristics.

After the pilot study results are evaluated, a full-scale dose–response study is planned in Xuan Wei. The full-scale study will involve collection and analysis of all of the types of data described above. The task of integrating the various types of data will be formidable, but given the unique nature of the study setting in Xuan Wei, the results are expected to yield unusually accurate, specific dose–response relationships. Project results are also expected to be beneficial to both China and the United States.

## ACKNOWLEDGMENTS

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